

BEHAVIORAL CONTRAST: PAVLOVIAN EFFECTS AND ANTICIPATORY CONTRAST

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Two sources of behavioral contrast have been identified previously: Pavlovian stimulus–reinforcer relations and component sequence effects (anticipatory contrast). This study sought to isolate these sources of control procedurally in a four-ply multiple schedule composed of two fixed two-component sequences. Different cues were associated with the first component of each sequence, and contrast effects were studied in these target components. In Experiment 1, differential cuing of Component 2 between sequences and availability of reinforcement during target components were varied across three groups of pigeons; the stimulus–reinforcer relation between target-component cues and schedule of reinforcement in Component 2 was varied within subjects. Control by the Pavlovian relation was demonstrated under all conditions, and anticipatory contrast was not observed. In Experiment 2, target-component duration was systematically varied in the three groups of Experiment 1. Control by the Pavlovian relation was reliably obtained only when target-component behavior was unreinforced, and diminished with increases in component duration. Anticipatory contrast emerged in the two groups for which target-component reinforcement was available. These and other data indicate that Pavlovian effects in multiple schedules may be obscured when the requisite conditions for anticipatory contrast are present.

Key words: behavioral contrast, stimulus–reinforcer relations, Pavlovian contingencies, anticipatory contrast, multiple schedules, component duration, key peck, pigeons

Behavioral contrast is a form of multiple schedule interaction in which rate of operant responding during one component of a multiple schedule (the target component) varies as a function of changes in the schedule of reinforcement associated with the other component(s). In a large body of literature, contrast has been attributed to numerous factors, including relative rate of reinforcement in the target component (Nevin, 1968; Reynolds, 1961), relative rate of reinforcement in the component following the target component (Williams, 1979; Wilton & Gay, 1969), frustration resulting from unreinforced responding in extratarget components (Terrace, 1966),

displacement of nonoperant responding from the target component to components associated with lower rates of reinforcement (Henton & Iversen, 1978; Hinson & Staddon, 1978), and interaction between Pavlovian and operant contingencies embedded in multiple schedule procedures (Gamzu & Schwartz, 1973; Hemmes, 1973). None of these factors is independent of the others, and, not surprisingly, none has provided a satisfactory account for all empirical data generated by multiple schedules.

The present study is an attempt to isolate procedurally the behavioral effects of two proposed determinants of behavioral contrast—Pavlovian stimulus–reinforcer ($S-S^R$) contingencies and component sequence effects. Previous studies suggest that both mechanisms may operate simultaneously, and possibly in opposition. The role of $S-S^R$ relations in multiple schedule interaction has been demonstrated by Brown, Hemmes, Coleman, Hassin, and Goldhammer (1982), Marcucella (1981), and Ortega and Marcucella (1987). In these studies, rate of key-peck responding during one component without reinforcement varied as a function of the $S-S^R$ relation between the cue

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associated with that component and probability of reinforcement in a succeeding component of a multiple schedule. Brown *et al.* (1982, Experiment 1) exposed pigeons to four-ply multiple schedules composed of two fixed two-component sequences. The first (target) component of each sequence was differentially cued by a red or green keylight and was 8 s in duration. Responses were never reinforced during these target components. The second component (the following component) of each sequence was cued by a white keylight and was 30 s in duration. Key-peck responses could be reinforced according to a variable-interval (VI) schedule during some following components. Of interest was rate of responding directed toward a red or green target-component cue as a function of its correlation with reinforcement in the following component. When the red and green cues were followed by identical VI schedules of reinforcement, little or no responding was directed toward those cues; however, when only one target-component cue was followed by a VI schedule and the other color was followed by extinction (EXT), high rates of responding were directed toward the target-component cue preceding the VI schedule. Based on this and other manipulations, Brown *et al.* concluded that Pavlovian S-S^R relations embedded in multiple schedules may contribute to multiple schedule interaction.

The role of component sequence effects in multiple schedule interaction has been well documented by Wilton and Gay (1969), Farley (1980), and Williams (1976, 1979, 1981). Like Brown *et al.* (1982), these investigators exposed pigeons to multiple schedules with three or more components; however, unlike Brown *et al.*, these studies generally showed higher rates of responding in target components followed by components associated with low versus high rates of reinforcement. This effect is termed anticipatory contrast. Williams (1990) addressed the apparent conflict between anticipatory contrast and the data reported by Brown *et al.* by focusing on procedural differences between the relevant studies. Studies showing anticipatory contrast have usually employed multiple schedules in which all components were equal in duration, and all were differentially cued. As pointed out by Williams, under such conditions the S-S^R contingency between a target-component cue and reinforcement in the following component is weak

(see also Gibbon & Balsam, 1981; Gibbon, Berryman, & Thompson, 1974; Rescorla, 1967; Rescorla & Wagner, 1972). In contrast, Brown *et al.* employed target components that were of short duration relative to the following components. In addition, although target components of each sequence were differentially cued (red vs. green keylights), the following components were not (a white keylight in both sequences). These conditions establish a strong S-S^R contingency between a target-component cue and reinforcement in the following component; that is, color of a short duration target-component cue is the only reliable predictor of reinforcement in the succeeding component.

Williams (1990) systematically examined the effects of these procedural differences in a 2 × 2 factorial design. One factor was target-component duration (10 or 30 s) relative to following-component duration (always 30 s). The other factor was presence or absence of differential cues associated with the following components. Anticipatory contrast (*i.e.*, higher rates of responding in the target stimulus preceding a low-density [VI 6-min] vs. a high-density [VI 30-s] component) was found under most conditions; however, some subjects (4 of 16) showed evidence of control by a Pavlovian relation under the condition most closely resembling the Brown *et al.* (1982) procedure—short target components and nondifferentially cued following components. As Williams pointed out, this was the condition providing the strongest predictive relation between target-component cues and reinforcement probability in the succeeding components.

Williams (1990) summarized his findings in terms of an interaction between two opposing behavioral effects controlled by multiple schedules—those determined by component sequence (anticipatory contrast) and those governed by Pavlovian contingencies. According to this analysis, the anticipatory contrast effect (defined in this paper as observation of higher rates of responding during target components preceding a low- vs. a high-reinforcement rate component) should dominate when a weak Pavlovian relation is arranged between target-component stimuli and reinforcement in the following components. Pavlovian effects (higher rates of responding during target components preceding a high- vs. a low-reinforcement rate component) should emerge in the presence of a strong S-S^R relation.

This notion was explored in the present study, in which the strength of the Pavlovian contingency was systematically varied by manipulation of three parameters: target-component duration, differential cuing of the following components, and availability of reinforcement for responses emitted during the target components. Two of these—target-component duration and differential cuing of the following components—were explored by Williams (1990); however, in Williams' study, these manipulations were performed in the context of multiple schedules that provided reinforcement for responding during both target components. Under those conditions, in which reinforcers were presented with equal probability in the presence of each target cue, any differential relation between a target-component cue and reinforcement delivery in the following components would be degraded. Thus, by Williams' analysis, this procedure would favor emergence of anticipatory contrast. Because of these considerations, the effects of reinforcer presentation during target components were also explored in the present study.

EXPERIMENT 1

In this experiment we systematically replicated Experiment 1 of Brown et al. (1982) to determine if Pavlovian effects would be obtained under multiple schedule procedures more closely approximating those used by Williams in his series of studies. Three groups of pigeons were exposed to multiple schedules composed of two two-component sequences. The duration of the target component (Component 1) of each sequence was 6 s, and the following component (Component 2) was 30 s in duration. Target components were differentially cued across sequences with red and green keylights. Groups differed in availability of reinforcement for pecking during target components, and presence of cues differentially signaling Component 2 of the two sequences. The procedure for Group 1 closely approximated that used by Brown et al. Responses were never reinforced during target components, and Component 2 cues did not differ between sequences. Conditions for Group 2 were identical except that responses directed to target-component stimuli were reinforced according to a low density random-interval (RI) schedule. This condition is similar to that un-

der which Williams (1979, 1990) found evidence of Pavlovian effects. The procedure for Group 3 was identical to that for Group 2 except that Component 2 was differentially cued across sequences with blue and yellow keylights. Pavlovian effects have not previously been observed under these conditions (cf. Williams, 1979, 1990).

In order to demonstrate multiple schedule interaction based on a Pavlovian relation, a within-subject reversal design was used. Pigeons in each group were initially exposed to a baseline phase (Phase B1) in which both target components preceded identical RI schedules of reinforcement in Component 2; that is, no S-S^R contingency was present between target-component cues and reinforcement in the following components. In Phase C1, the schedule of reinforcement in Component 2 of one two-component sequence was converted from RI to EXT. This manipulation constituted introduction of a Pavlovian relation between Component 1 cues and schedule of reinforcement in Component 2. Baseline conditions were reinstated during Phase B2, and in Phase C2 the Pavlovian relation was re-introduced with a stimulus reversal in the target components. As pointed out by Schwartz and Gamzu (1977), the within-subject reversal design provides the least equivocal evidence of multiple schedule interaction.

Method

Subjects. Twelve naive White Carneau pigeons were maintained at 80% of ad-lib weights.

Apparatus. The experiment was conducted in two standard three-key pigeon chambers (BRS/LVE). The right key could be transilluminated with various stimuli by means of a display projector (BRS/LVE IC-901). The left and center keys remained dark and responses directed toward these keys were not recorded and had no programmed consequence. Responses of at least 0.10 N to the right key were recorded. The reinforcer was 2-s access to mixed grain delivered by a food hopper located directly below the center key. The houselight remained on during the entire session except during reinforcement, when the houselight and keylight were extinguished and the food hopper was illuminated. Masking noise was provided by chamber fans and white noise in the chambers and in the room con-

taining the chambers. Electromechanical programming and recording equipment was located in an adjacent room.

Procedure. All birds were magazine trained and were trained to peck the right key, which was illuminated with white light, via hand-shaping. They were then exposed to three pretraining schedules prior to the experimental phases. The first pretraining schedule was RI 30 s, under which reinforcement availability was determined by sampling a probability generator set at .10 ($p = .10$) at the beginning of each 3-s interval ($t = 3$ s). Session length was 55 min. After a bird earned 50% of available reinforcers under the RI 30-s schedule, it was transferred to a mixed schedule for the next 42 sessions. Under this schedule, a 6-s EXT component alternated with a 30-s RI 30-s component. Reinforcers not earned during an RI component were canceled. During the next 35 pretraining sessions, the mixed schedule was converted to a multiple schedule by presenting a black cross on a white background during the EXT component. Conditions were otherwise unchanged.

Following pretraining, 4 birds were randomly assigned to one of three groups (Groups 1, 2, and 3) and exposed to a four-ply multiple schedule. This schedule was comprised of two fixed two-component sequences that alternated. Component 1 (the target component) of each sequence was 6 s in duration and was signaled by a red or green keylight. Schedule of reinforcement during the target components differed across groups as described below. The second component of each sequence was 30 s in duration. Ninety sequences were presented in each session during all phases of this experiment.

Component 2 cues and schedules differed across groups and experimental phases (see Table 1). For birds in Group 1, EXT was programmed during the target components, and RI 150 s ($t = 3$ s; $p = .02$) was scheduled during target components for birds in Groups 2 and 3. Component 2 presentations were non-differentially cued with a white keylight across sequences for birds in Groups 1 and 2. Therefore these birds were exposed to repetitions of the following sequence: red (6 s), white (30 s), green (6 s), white (30 s). For birds in Group 3, Component 2 presentations were differentially cued across sequences with blue and yellow keylights, so that the following sequence

was presented: red (6 s), blue (30 s), green (6 s), yellow (30 s).

Four experimental phases were presented that differed in presence or absence of a differential relation between target-component cue color and schedule of reinforcement in Component 2. Phases B1 and B2 (35 and 30 sessions, respectively) were baseline conditions during which no differential relation was present; RI 30 s ($t = 3$ s; $p = .10$) was programmed for Component 2 of both sequences. During the manipulation phases—Phases C1 and C2 (30 and 25 sessions, respectively)—a differential relation was arranged by changing the Component 2 schedule of one sequence to EXT. During Phase C1 the red target-component cue was associated with RI 30 s during Component 2 for half of the birds in each group. For the other birds the red cue preceded EXT in Component 2. The relation between target-component cue color and Component 2 schedule was reversed during Phase C2. These experimental manipulations are summarized in Table 1. Conditions were changed according to a prearranged schedule, so a stability criterion was not used. Variability was assessed using statistical tests. Individual variations may be seen in the figures.

Results

Introduction of a differential relation between target-component cues and reinforcement in the following components produced similar effects on responding during the target components for birds in all groups. This can be seen in Figure 1, which shows mean rate of responding during target components for individual birds plotted in five-session blocks. Data from all of the birds in a single group are presented in one column, with group functions plotted in the bottom panel of each column. Although detailed findings appear to differ across groups, introduction of the Pavlovian relation (Phases C1 and C2) generally resulted in an increase in responding during the target component of the RI sequence and no change or a decrease in rate of responding during the target component of the EXT sequence. When the contingency was removed (Phase B2), behavior in the target components for most birds approached that observed in Phase B1.

A Group \times Replication (B1 and C1 vs. B2 and C2) \times Condition (baseline vs. contingency) \times Sequence (RI vs. EXT in Compo-

Table 1
Summary of experimental conditions for Experiment 1.

	Sequence A		Sequence B		Subjects
	Target component	Component 2	Target component	Component 2	
Group 1					
Phase B1 (35) ^a					
Cue	Red	White	Green	White	1, 2, 3, 4
Schedule	EXT	RI 30	EXT	RI 30	
Duration	6 s	30 s	6 s	30 s	
Phase C1 (30)					
Cue	Red	White	Green	White	1, 2 3, 4
Schedule	EXT	EXT	EXT	RI 30	
Schedule	EXT	RI 30	EXT	EXT	
Duration	6 s	30 s	6 s	30 s	
Phase B2 (30)					
Cue	Red	White	Green	White	1, 2, 3, 4
Schedule	EXT	RI 30	EXT	RI 30	
Duration	6 s	30 s	6 s	30 s	
Phase C2 (25)					
Cue	Red	White	Green	White	1, 2 3, 4
Schedule	EXT	RI 30	EXT	EXT	
Schedule	EXT	EXT	EXT	RI 30	
Duration	6 s	30 s	6 s	30 s	
Group 2					
Phase B1 (35)					
Cue	Red	White	Green	White	5, 6, 7, 8
Schedule	RI 150	RI 30	RI 150	RI 30	
Duration	6 s	30 s	6 s	30 s	
Phase C1 (30)					
Cue	Red	White	Green	White	5, 6 7, 8
Schedule	RI 150	EXT	RI 150	RI 30	
Schedule	RI 150	RI 30	RI 150	EXT	
Duration	6 s	30 s	6 s	30 s	
Phase B2 (30)					
Cue	Red	White	Green	White	5, 6, 7, 8
Schedule	RI 150	RI 30	RI 150	RI 30	
Duration	6 s	30 s	6 s	30 s	
Phase C2 (25)					
Cue	Red	White	Green	White	5, 6 7, 8
Schedule	RI 150	RI 30	RI 150	EXT	
Schedule	RI 150	EXT	RI 150	RI 30	
Duration	6 s	30 s	6 s	30 s	
Group 3					
Phase B1 (35)					
Cue	Red	Blue	Green	Yellow	9, 10, 11, 12
Schedule	RI 150	RI 30	RI 150	RI 30	
Duration	6 s	30 s	6 s	30 s	
Phase C1 (30)					
Cue	Red	Blue	Green	Yellow	9, 10 11, 12
Schedule	RI 150	RI 30	RI 150	EXT	
Schedule	RI 150	EXT	RI 150	RI 30	
Duration	6 s	30 s	6 s	30 s	
Phase B2 (30)					
Cue	Red	Blue	Green	Yellow	9, 10, 11, 12
Schedule	RI 150	RI 30	RI 150	RI 30	
Duration	6 s	30 s	6 s	30 s	
Phase C2 (25)					
Cue	Red	Blue	Green	Yellow	9, 10 11, 12
Schedule	RI 150	EXT	RI 150	RI 30	
Schedule	RI 150	RI 30	RI 150	EXT	
Duration	6 s	30 s	6 s	30 s	

^a Number of sessions per phase is listed parenthetically.

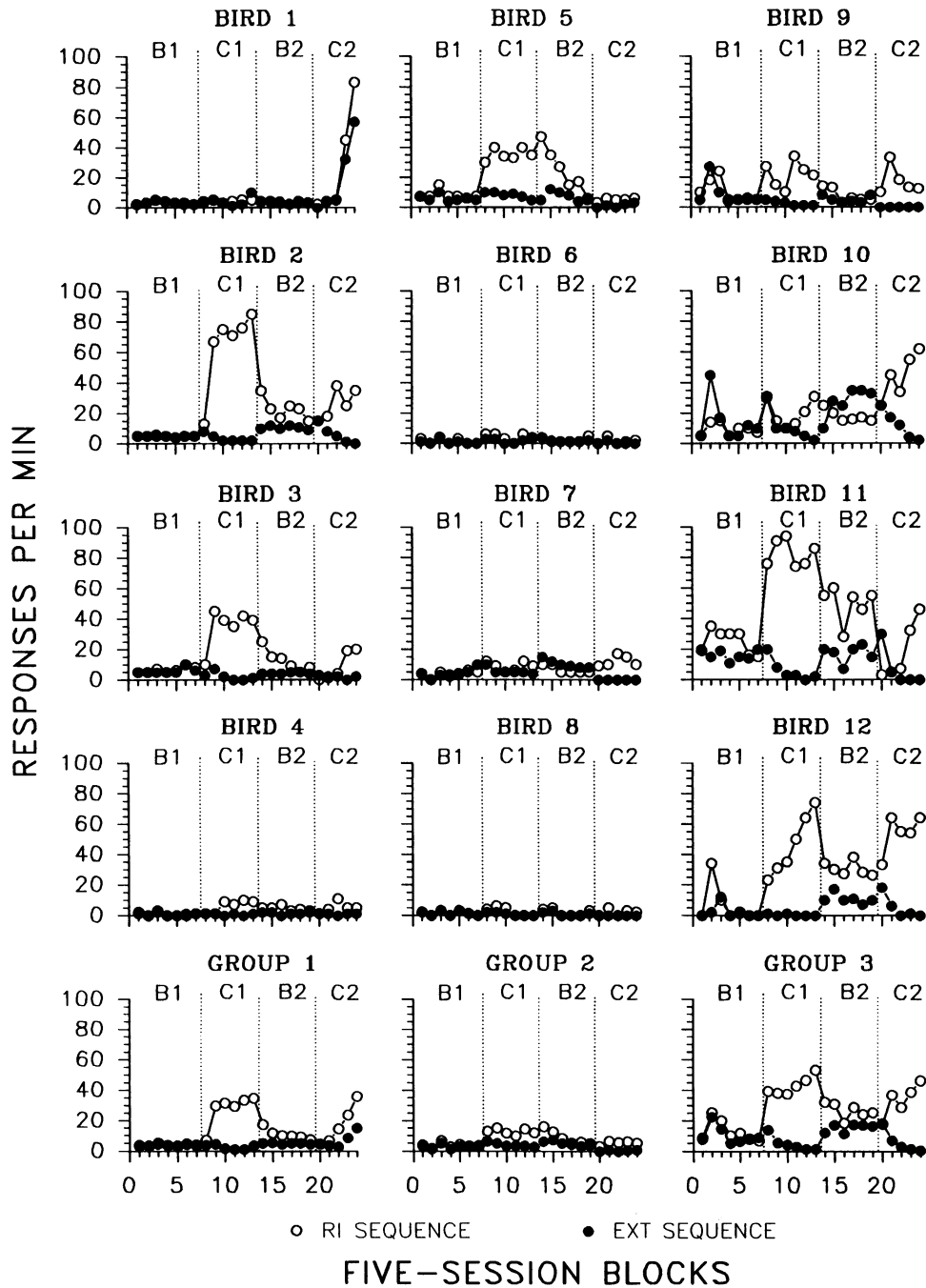


Fig. 1. Mean rate of responding during target components, plotted in five-session blocks for Experiment 1. Data for individual birds in each group are presented in one column, and group functions are plotted in the bottom panel of each column. Dotted vertical lines indicate phase changes. Open and filled circles represent the RI and EXT sequences, respectively. Cues associated with each sequence were reversed in Phase C2.

nent 2) analysis of variance (ANOVA) for target-component rate of responding during the last five sessions of each phase revealed significant main effects for Condition, $F(1, 9) =$

10.33, $p < .05$, and Sequence, $F(1, 9) = 16.51$, $p < .01$, and a significant Condition \times Sequence interaction, $F(1, 9) = 24.41$, $p < .001$. The contribution of groups approached con-

Table 2

Number of reinforcements per minute times 10 and, in parentheses, reinforcers per session during target components, Experiment 1.

Group 2	Seq. ^a	Bird 5	Bird 6	Bird 7	Bird 8	<i>M</i>
Phase B1	RI	0.4 (0.2)	0.4 (0.2)	0 (0)	0 (0)	0.2 (0.1)
	RI	0.9 (0.4)	0.4 (0.2)	0.4 (0.2)	0 (0)	0.4 (0.2)
Phase C1	RI	2.7 (1.2)	2.7 (1.2)	0.4 (0.2)	0.9 (0.4)	1.7 (0.7)
	EXT	1.3 (0.6)	0 (0)	0 (0)	0 (0)	0.3 (0.1)
Phase B2	RI	0.9 (0.4)	2.2 (1.0)	0.4 (0.2)	0.9 (0.4)	1.1 (0.5)
	RI	4.0 (1.8)	2.7 (1.2)	2.2 (1.0)	0 (0)	2.2 (1.0)
Phase C2	RI	2.7 (1.2)	2.2 (1.0)	0.9 (0.4)	0.4 (0.2)	1.6 (0.7)
	EXT	0.4 (0.2)	0 (0)	0 (0)	0 (0)	0.1 (0.1)
Group 3	Seq. ^a	Bird 9	Bird 10	Bird 11	Bird 12	<i>M</i>
Phase B1	RI	0 (0)	0.4 (0.2)	0.9 (0.4)	0 (0)	0.3 (0.1)
	RI	0.4 (0.2)	1.3 (0.6)	0.9 (0.4)	0.4 (0.2)	0.8 (0.3)
Phase C1	RI	3.6 (1.6)	4.0 (1.8)	1.8 (0.8)	2.2 (1.0)	2.9 (1.3)
	EXT	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Phase B2	RI	0.4 (0.2)	0.9 (0.4)	1.8 (0.8)	2.2 (1.0)	1.3 (0.6)
	RI	2.7 (1.2)	3.1 (1.4)	4.0 (1.8)	3.6 (1.6)	3.3 (1.3)
Phase C2	RI	3.6 (1.6)	3.6 (1.6)	1.8 (0.8)	2.2 (1.0)	2.8 (1.3)
	EXT	0 (0)	0 (0)	0.4 (0.2)	0 (0)	0.1 (0.1)

^a "Seq." refers to schedule of reinforcement in Component 2.

ventional levels of significance, $F(2, 9) = 4.08$, $p = .055$, and there was a significant Group \times Condition \times Sequence interaction, $F(2, 9) = 4.72$, $p < .05$. None of the effects involving the replication were statistically significant. Individual contrast tests yielded a reliable Condition \times Sequence interaction for Group 1, $F(1, 9) = 7.43$, $p < .05$, and Group 3, $F(1, 9) = 25.87$, $p < .01$, but not for Group 2, $F(1, 9) = 0.55$.

Because rates of responding were highly variable (particularly in Groups 1 and 2), the results were also evaluated in terms of discrimination ratios computed as target-component rate during the RI sequence divided by target rate during both sequences. Based on the last five sessions of each phase, there was a significant main effect for condition, $F(1, 9) = 38.51$, $p < .001$, but no significant effects based on replication or group. Individual contrasts revealed significant ($p < .01$) effects of condition for all groups, $F(1, 9) = 9.75$, 7.12, and 24.60, respectively, for Groups 1, 2, and 3.

Table 2 presents rate of reinforcement (reinforcers per minute times 10) and number of reinforcers per session in target components during the last five sessions of each phase. Reinforcer rates were low for all birds, occasionally reaching zero.

Figure 2 shows mean rate of responding during the Component 2 stimuli for each group

of birds. With introduction of EXT in Component 2 of one sequence (Phases C1 and C2), most birds showed a marked decrease in rate of responding during the changed (EXT) Component 2 and an increase in rate during the unchanged (RI) Component 2. This differential behavior was statistically significant for all groups. An ANOVA produced a significant Condition \times Sequence interaction, $F(1, 9) = 37.37$, $p < .001$, and no Group \times Condition \times Sequence nor Group \times Replication \times Condition \times Sequence interactions. Separate analyses for each group produced significant ($p < .05$) Condition \times Sequence interactions.

Discussion

These findings replicate and extend those of Brown et al. (1982) in demonstrating multiple schedule interaction as a function of a Pavlovian manipulation. Addition of reinforcer availability during target components (Groups 2 and 3) and of discriminative stimuli during the terminal components (Group 3) did not eliminate the Pavlovian effect; rates of target-component responding were higher during the RI than during the EXT sequence when the stimulus-reinforcer contingency was in place (Phases C1 and C2). However, as in the study by Brown et al., there was interbird variability in rate of responding.

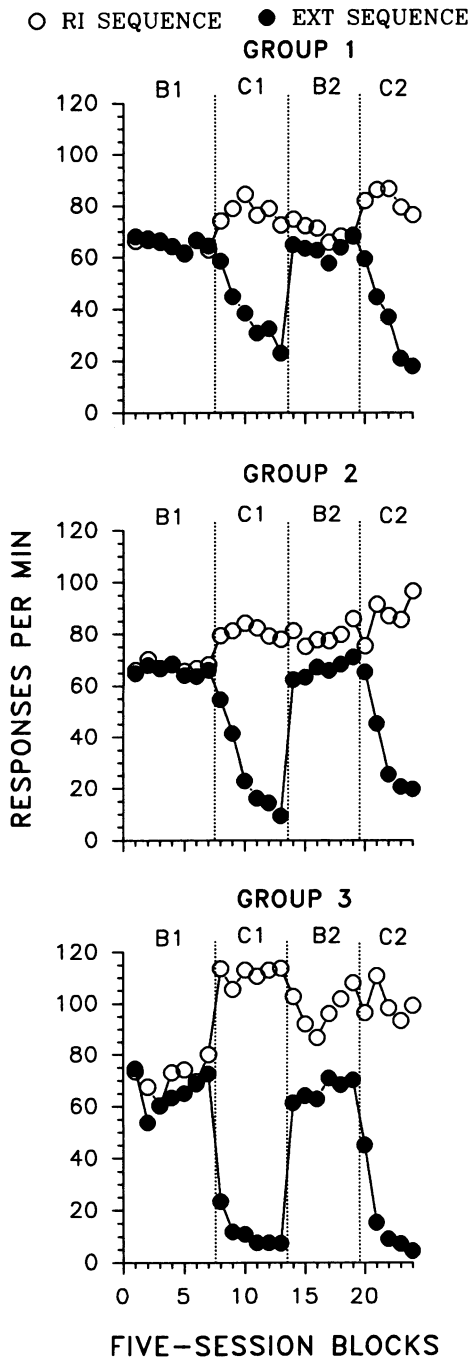


Fig. 2. Group mean rates of responding during Component 2 of each sequence plotted in five-session blocks for Experiment 1. Dotted vertical lines indicate phase changes. Open and filled circles represent the RI and EXT sequences, respectively. Cues associated with each sequence were reversed in Phase C2.

Interpretation of these results in terms of Pavlovian theory is not straightforward, owing to lack of consensus on the manner in which S-S^R relations should be specified. In contingency theory, the S-S^R relation is defined in terms of conditional probabilities of reinforcement in the presence of a conditioned stimulus and in its absence (see Rescorla, 1967; but see Papini & Bitterman, 1990, who challenge contingency theory as an adequate account of the conditions underlying Pavlovian conditioning). Excitatory conditioning is predicted when probability of reinforcement in the presence of a cue is high relative to reinforcement probability in its absence. Stated in this manner, contingency theory clearly does not apply to the present study, in which the probability of reinforcement was very low or zero in the presence of target-component stimuli and high in their absence.

If the requirement of temporal contiguity between a target stimulus and the reinforcer is relaxed, predictions for the present situation can be based on the sequential dependencies between target-component cues and reinforcement. This was the approach taken by Williams (1990) in accounting for differences in the data reported by Brown *et al.* (1982) and by Williams (1979). As Williams (1990) pointed out, when the following components are nondifferentially cued (as in Group 1), the positive target-component cue serves as the most reliable predictor of reinforcement in that situation; however, when differential cues are added to the following components (as in Group 3), the relative predictiveness of target-component cues is reduced. Under this latter condition, differential cuing of following components "... should serve to overshadow any learning of the association between the target stimuli and the different following schedules" (Williams, 1990, p. 45). Under this analysis, evidence for Pavlovian control of target-component behavior should be strongest in Group 1. However, this was not the case; Pavlovian effects were at least as great for Group 3 as for Group 1. Of course, performance in Group 3 was also subject to control by the response-reinforcer contingency programmed during target components for this group; nonetheless, target-component behavior varied reliably with changes in the S-S^R relation across experimental phases.

In the foregoing analysis, target-component

responding is assumed to be controlled by experience with conditions in the following component. Alternatively, control may be attributed to conditions in the preceding component because of the fixed order of sequence presentation used in the present study. Although logical, this interpretation is implausible for several reasons. First, Williams (1979, 1981) evaluated the relative contributions to multiple schedule interaction of preceding and following components and found no consistent effect of the preceding component. Second, Williams (1979) demonstrated both anticipatory contrast and Pavlovian-like effects when conditions in the preceding component were not fixed. Finally, the present results replicate those of Brown et al. (1982), who used random alternation between sequences.

Although not a primary focus of the present report, the systematic differentiation observed in Component 2 between sequences is worth noting, particularly for Groups 1 and 2. Recall that for these birds, Component 2 was non-differentially cued across sequences. Similar results were reported by Brown et al. (1982), who evaluated two possible bases for this effect: discriminative control by reinforcer delivery during Component 2 and discriminative control based on target-component events (either key color or characteristics of the birds' behavior). Qualitative and quantitative analyses favored the latter alternative.

EXPERIMENT 2

Experiment 2 sought to reconcile the discrepant outcomes of the present study and those of Williams (1979, 1990). Although conditions for Group 3 of Experiment 1 were similar to those of the 10-signal condition under which Williams (1990) observed anticipatory contrast, some functional differences may nonetheless exist. In Williams' procedure, target-component duration was 10 s (vs. 6 s in the present study), and the schedule of reinforcement was VI 2 min (vs. RI 150 s in the present study). Either of these differences alone may have contributed to the present failure to replicate Williams' results, but they also may have interacted to produce an even greater difference in rate of obtained reinforcement than that arranged by the nominal schedule values. As shown in Table 2, birds in Group 3 produced extremely low rates of target-component

reinforcement, especially during the component preceding EXT in Component 2, in which they earned far fewer than one reinforcer per session. Although Williams did not present data on obtained reinforcement rate, his birds responded at high rates during the target component preceding EXT in Component 2 and probably earned most of the three or four reinforcers per session that would be arranged by the VI 2-min schedule.

This difference in rate of earned reinforcement may be important. Although anticipatory contrast has been found under a variety of conditions (cf. Farley, 1980; Pliskoff, 1963; Williams, 1979, 1981; Wilton & Gay, 1969), those conditions have in common a transition from a nonzero schedule of reinforcement in the target component of interest to a lower density of reinforcement in the succeeding component. In other words, anticipatory contrast *may* occur only in a target component that is followed by a period in which rate of reinforcement is even lower. This condition was probably not met in Experiment 1. Even though target-component reinforcers were scheduled for birds in Groups 2 and 3, they were rarely earned during the target component preceding EXT (see Table 2). Therefore, the target component in which anticipatory contrast would be expected to occur was in fact followed by little or no change in rate of reinforcement during Component 2.

This analysis was investigated in Experiment 2. The birds used in Experiment 1 were exposed to the stimulus and schedule values in effect during the last phase of that experiment (Phase C2), while target-component duration was systematically varied. Four values were presented across 20-session blocks: 12, 18, 30, and 6 s. Increasing target-component duration (12, 18, and 30 s) provided greater opportunity for birds in Groups 2 and 3 to earn reinforcers.

A second goal of this experiment was to study the functional relation between target-component duration and multiple schedule interaction under conditions most closely approximating those studied by Brown et al. (1982) and those used by Wilton and Gay (1969) and Williams in his series of studies. In a related study, Ortega and Marcucella (1987) exposed pigeons to a three-component schedule composed of a 1.5-s target component without reinforcement and two 60-s following

components. In agreement with the results of Brown *et al.*, Marcucella (1981), and the present study, target-component responding was acquired when the target cue signaled a transition to a higher rate of reinforcement. When duration of the target component was varied from 1.5 to 50 s, rate of responding varied inversely with target-component duration. These findings are consistent with the analysis of multiple schedule interaction in terms of control by $S-S^R$ relations. Both theory and data predict that increases in stimulus-reinforcer delay relative to interreinforcer time (Gibbon, Baldock, Locurto, Gold, & Terrace, 1977; Gibbon & Balsam, 1981) or to other signaled delays (Brown *et al.*) will result in decreased strength of responding.

Experiment 2 extended Ortega and Marcucella's (1987) demonstration by studying the effects of target-component duration on target stimuli preceding transitions to both higher and lower rates of reinforcement. This is important because evidence for anticipatory contrast is restricted to target cues signaling transition to a lower rate of reinforcement.

Method

Subjects and apparatus. The subjects were those used in Experiment 1, and the apparatus was the same as that used for Experiment 1.

Procedure. In the presence of a differential relation between target-component cue color and Component 2 schedule (the same conditions as the last phase—Phase C2—of the previous experiment), duration of both target components was varied across four values. Durations of 12, 18, 30, and 6 s were presented in that order, with each duration in effect for 20 consecutive sessions. Total number of components per session varied with component duration, as indicated in Table 3. Finally, with component duration at 6 s, the differential relation was removed by presenting identical RI 30-s schedules during Component 2 of each sequence (Phase B3, 20 sessions). These conditions are summarized in Table 3.

Results

The effects of target-component duration on behavior during the target component can be seen in Figure 3, which shows mean rate of responding for individual birds plotted in five-session blocks. Data for all birds in a single group are presented in one column, and group

functions are plotted in the bottom panel of each column. Target-component duration is indicated between the dashed lines that separate the data into phases. Data for the first 6-s duration condition are taken from the last phase of Experiment 1. The effects of increasing target-component duration from 6 to 30 s differed across groups and across birds within a group. For birds in Group 1 (EXT during target components), the manipulation produced a systematic decrease in rates of responding during both target components and no evidence of anticipatory contrast. When the 6-s condition was reinstated, previous performance was recovered (except for Bird 4). Birds in Groups 2 and 3 (RI 150 s during target components) showed Pavlovian effects (higher target-component rates during the RI vs. the EXT sequence) during the initial 6-s condition that gave way, for 6 of 8 birds, to anticipatory contrast (higher rates during the target component that preceded EXT) as component duration was increased. When the 6-s condition was reinstated, both anticipatory contrast and a Pavlovian effect were observed, but neither consistently.

Group differences were confirmed by a significant Group \times Duration \times Sequence interaction based on mean response rate from the last five sessions under the 6- (C2), 12-, 18-, and 30-s duration conditions, $F(6, 9) = 3.04$, $p < .05$. Significant Duration \times Sequence interactions were found for Group 1, $F(3, 9) = 9.08$, $p < .01$, and Group 3, $F(3, 9) = 14.02$, $p < .001$. No significant effects were found for Group 2. For Group 3, Pavlovian control of target-component behavior yielded to an anticipatory contrast effect as component duration was lengthened. Based on means from the last five sessions of Conditions 18 and 30, there was a statistically significant sequence effect, $t(3) = 6.16$; $p < .01$, two-tailed.

Reinstatement of the 6-s target-component duration produced different effects in Groups 1 and 3. Although both groups showed Pavlovian effects during the first exposure to this condition (Phase C2, Experiment 1), only Group 1 showed recovery upon a return to the 6-s condition. For that group, a significant Sequence effect was obtained across initial and reinstatement conditions, $F(1, 3) = 10.49$, $p < .05$, with no consistent Condition \times Sequence interaction ($F < 1$). For Group 3, the

Table 3
Summary of experimental conditions for Experiment 2.

	Sequence A		Sequence B		Subjects
	Target component	Component 2	Target component	Component 2	
Group 1					
Duration manipulation					
Cue	Red	White	Green	White	1, 2 3, 4
Schedule	EXT	RI 30	EXT	EXT	
Schedule	EXT	EXT	EXT	RI 30	
Durations (in seconds):					
6 ^a (45/25) ^b	6	30	6	30	
12 (38/20)	12	30	12	30	
18 (34/20)	18	30	18	30	
30 (27/20)	30	30	30	30	
6 (45/20)	6	30	6	30	
Phase B3 (45/20) ^b					
Cue	Red	White	Green	White	1, 2, 3, 4
Schedule	EXT	RI 30	EXT	RI 30	
Duration	6	30	6	30	
Group 2					
Duration manipulation					
Cue	Red	White	Green	White	5, 6 7, 8
Schedule	RI 150	RI 30	RI 150	EXT	
Schedule	RI 150	EXT	RI 150	RI 30	
Durations (in seconds):					
6 ^a (45/25)	6	30	6	30	
12 (38/20)	12	30	12	30	
18 (34/20)	18	30	18	30	
30 (27/20)	30	30	30	30	
6 (45/20)	6	30	6	30	
Phase B3 (45/20)					
Cue	Red	White	Green	White	5, 6, 7, 8
Schedule	RI 150	RI 30	RI 150	RI 30	
Duration	6	30	6	30	
Group 3					
Duration manipulation					
Cue	Red	Blue	Green	Yellow	9, 10 11, 12
Schedule	RI 150	EXT	RI 150	RI 30	
Schedule	RI 150	RI 30	RI 150	EXT	
Durations (in seconds):					
6 ^a (45/25)	6	30	6	30	
12 (38/20)	12	30	12	30	
18 (34/20)	18	30	18	30	
30 (27/20)	30	30	30	30	
6 (45/20)	6	30	6	30	
Phase B3 (45/20)					
Cue	Red	Blue	Green	Yellow	9, 10, 11, 12
Schedule	RI 150	RI 30	RI 150	RI 30	
Duration	6	30	6	30 s	

^a Condition C2 of Experiment 1.

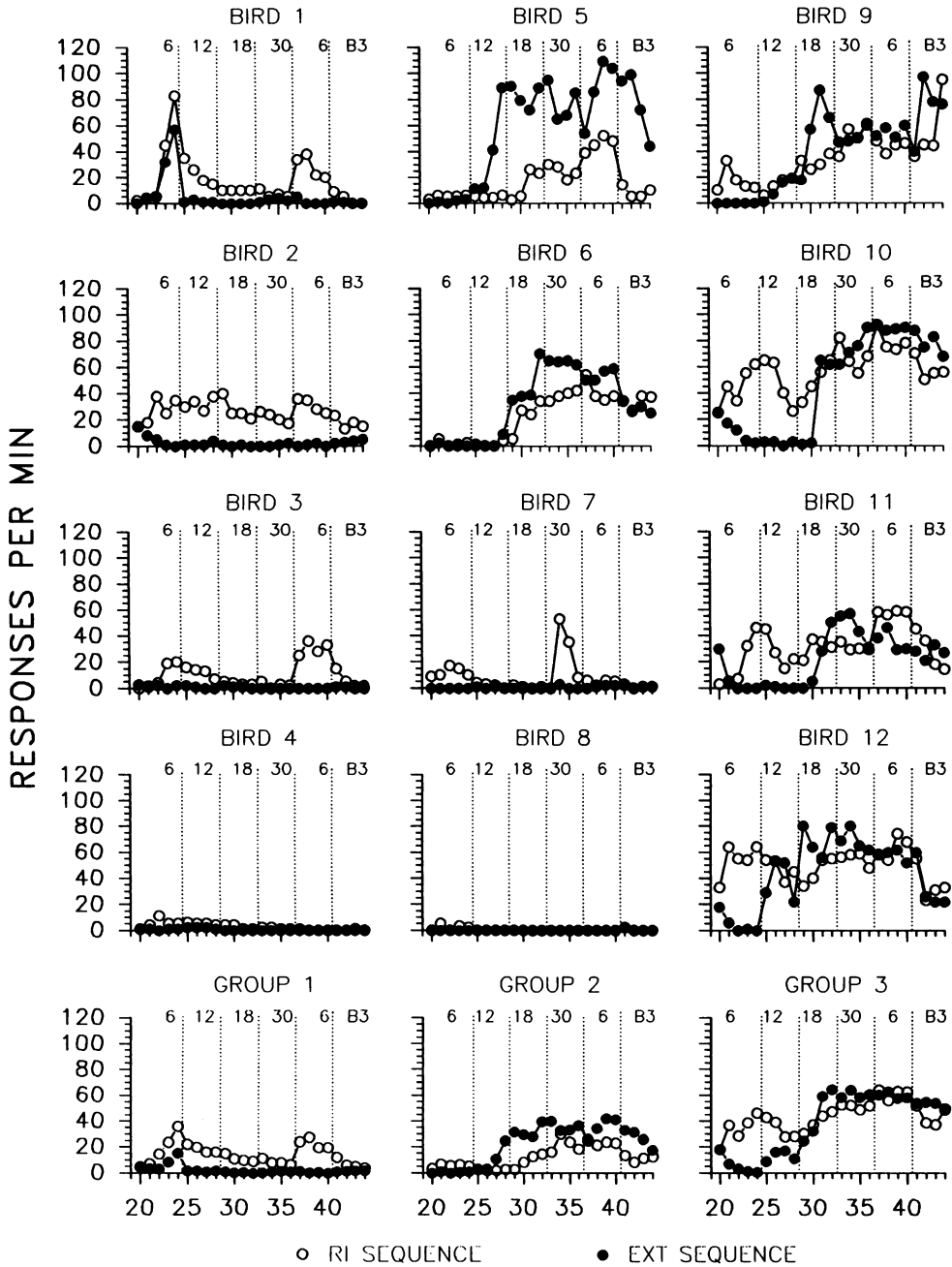
^b Number of components per session, followed by sessions per condition, are listed parenthetically.

interaction was statistically significant, $F(1, 3) = 11.44$, $p < .05$, and Sequence effect was not ($F < 1$).

During the final baseline phase (B3), reinforcement was available during Component

2 of both sequences. With one exception (Bird 9, Group 3), all birds that were responding in the previous phase showed a decline in response rate (Figure 3).

Table 4 presents rate of reinforcement (re-



FIVE-SESSION BLOCKS

Fig. 3. Mean rate of responding during target components, plotted in five-session blocks for Experiment 2. Data for individual birds in each group are presented in one column, and group functions are plotted in the bottom panel of each column. Dotted vertical lines indicate phase changes.

inforcers per minute times 10) and number of reinforcers per session in target components during the last five sessions of each condition. As anticipated, birds earned more reinforcers per session as component duration increased.

This effect was statistically significant for Group 3, $F(3, 9) = 154.02, p < .001$, with no Condition \times Sequence interaction, $F(3, 9) = 0.77$. The effect of Condition for Group 2 approached conventional levels of significance,

Table 4

Number of reinforcers per minute times 10 and, in parentheses, reinforcers per session during target components, Experiment 2.

Group 2	Seq. ^a	Bird 5	Bird 6	Bird 7	Bird 8	<i>M</i>
Phase 6a	RI	2.7 (1.2)	2.2 (1.0)	0.9 (0.4)	0.4 (0.2)	1.6 (0.7)
	EXT	0.4 (0.2)	0 (0)	0 (0)	0 (0)	0.1 (0.1)
Phase 12	RI	2.4 (1.8)	1.1 (0.8)	0.3 (0.2)	0 (0)	0.9 (0.7)
	EXT	5.5 (4.2)	2.4 (1.8)	0 (0)	0 (0)	2.0 (1.5)
Phase 18	RI	3.9 (4.0)	3.9 (4.0)	0.2 (0.2)	0 (0)	2.0 (2.1)
	EXT	4.9 (5.0)	4.5 (4.6)	0 (0)	0 (0)	2.3 (2.4)
Phase 30	RI	4.0 (5.4)	3.9 (5.2)	2.2 (3.0)	0.1 (0.2)	2.6 (3.4)
	EXT	2.5 (3.4)	2.7 (3.6)	0 (0)	0.1 (0.2)	1.3 (1.8)
Phase 6b	RI	3.1 (1.4)	1.8 (0.8)	0 (0)	0 (0)	1.2 (0.5)
	EXT	2.7 (1.2)	2.2 (1.0)	0 (0)	0 (0)	1.2 (0.5)
Phase B	RI	2.2 (1.0)	3.1 (1.4)	0.4 (0.2)	0 (0)	1.4 (0.7)
	RI	3.6 (1.6)	3.6 (1.6)	4.0 (1.8)	0 (0)	2.8 (1.3)
Group 3	Seq. ^a	Bird 9	Bird 10	Bird 11	Bird 12	<i>M</i>
Phase 6a	RI	3.6 (1.6)	3.6 (1.6)	1.8 (0.8)	2.2 (1.0)	2.8 (1.3)
	EXT	0 (0)	0 (0)	0.4 (0.2)	0 (0)	0.1 (0.1)
Phase 12	RI	1.6 (1.2)	1.6 (1.2)	0.8 (0.6)	0.8 (0.6)	1.2 (0.9)
	EXT	1.6 (1.2)	0 (0)	0 (0)	1.1 (0.8)	0.6 (0.5)
Phase 18	RI	4.9 (5.0)	5.3 (5.4)	2.4 (2.4)	2.7 (2.8)	3.8 (3.9)
	EXT	2.2 (2.2)	2.5 (2.6)	2.7 (3.8)	2.9 (3.0)	2.6 (2.7)
Phase 30	RI	4.7 (6.4)	4.6 (6.2)	5.0 (6.8)	4.9 (6.6)	4.8 (6.5)
	EXT	4.7 (6.4)	4.9 (6.6)	3.1 (4.2)	3.3 (4.4)	4.0 (5.4)
Phase 6b	RI	0.9 (0.4)	0.9 (0.4)	0.9 (0.4)	1.3 (0.6)	1.0 (0.5)
	EXT	3.1 (1.4)	3.6 (1.6)	4.0 (1.8)	5.3 (2.4)	4.0 (1.8)
Phase B	RI	1.8 (0.8)	2.2 (1.0)	0.4 (0.2)	1.3 (0.6)	1.4 (0.7)
	RI	1.8 (0.8)	1.8 (0.8)	0.4 (0.2)	1.8 (0.8)	1.4 (0.7)

^a "Seq." refers to schedule of reinforcement in Component 2.

$F(3, 9) = 25.25$, $p = .055$, and there was a significant Condition \times Sequence interaction, $F(3, 9) = 7.15$, $p < .05$. The interaction reflects a greater change in reinforcers earned during the RI sequence versus the EXT sequence as component duration increased. Similar results were obtained for the rate-of-reinforcement measure.

When the 6-s condition was reinstated, group mean rate of reinforcement during the EXT sequence was higher than it had been during the previous determination (Condition C2). This effect was statistically significant only for Group 3, $F(1, 3) = 62.25$, $p < .01$, two-tailed. During the reinstatement phase for that group, reinforcement rate during the RI sequence was lower than in the EXT sequence. This difference is not readily interpreted, but was unrelated to rate of responding.

Figure 4 shows mean rate of responding during Component 2 of both sequences for each group of birds. Although differentiation appears to be greatest for Group 3 (the only group for which Component 2 was differen-

tially cued), there was no statistically significant Group \times Condition \times Sequence interaction nor Group \times Sequence interaction. In separate analyses for each group, there was a significant main effect of Sequence for each group ($p < .05$).

Discussion

In this study, the effects of target-component duration on multiple schedule interaction depended on reinforcement conditions during the target components. When no reinforcers were presented (Group 1), target-component rate during the RI sequence exceeded that during the EXT sequence at all durations. When reinforcers were presented during target components (Groups 2 and 3), type of multiple schedule interaction appeared to vary with component duration. When target-component duration was increased from 6 to 30 s, an initial pattern of higher rates during the RI sequence was reversed as rate in the EXT sequence climbed and exceeded that in the RI sequence. However, when the 6-s condition

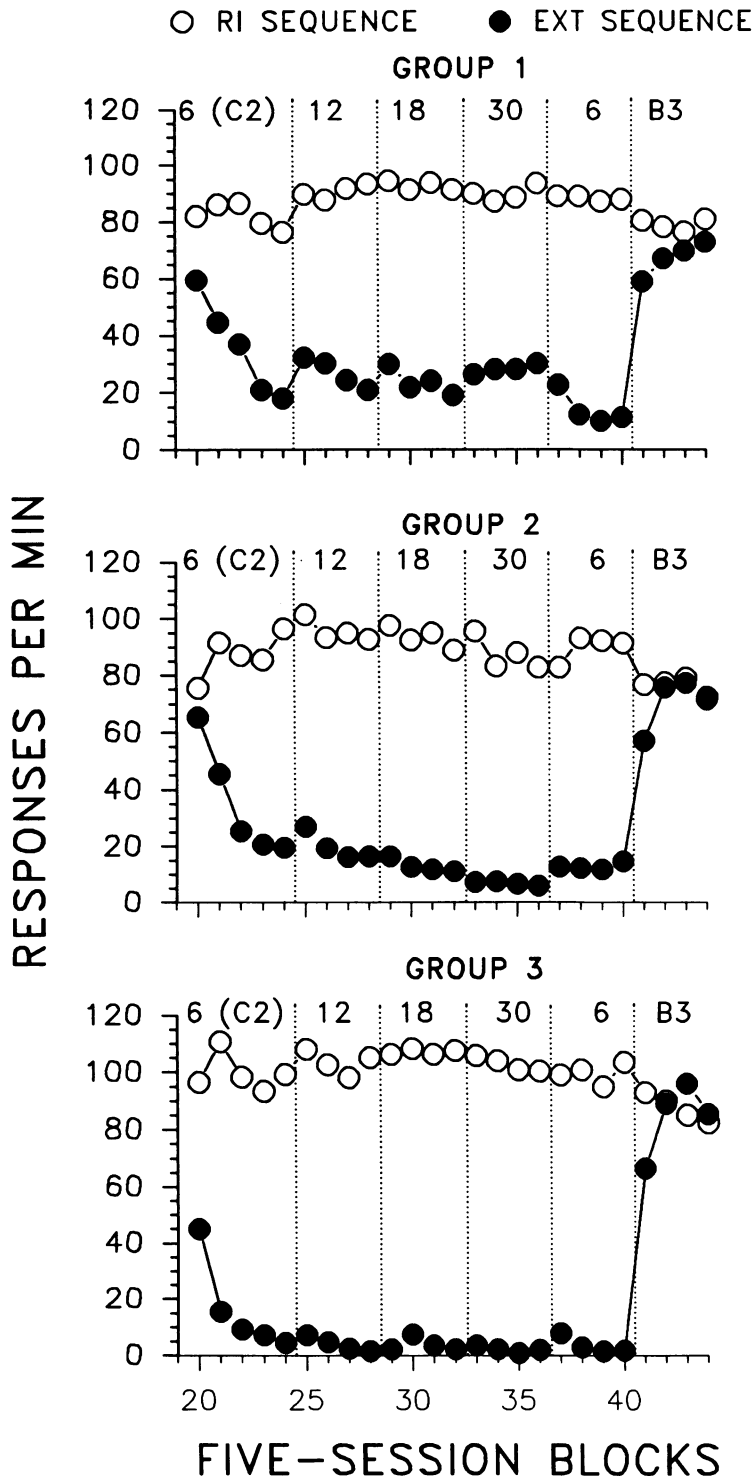


Fig. 4. Group mean rates of responding during Component 2 of each sequence plotted in five-session blocks for Experiment 2. Dotted vertical lines indicate phase changes.

was reinstated (Phase 6), the pattern observed during previous exposures to 6-s durations (Phases C1 and C2 of Experiment 1) was not replicated.

Data for birds in Group 1 are consistent with those of Ortega and Marcucella (1987) in demonstrating an inverse relation between target-component duration and rate of responding during the RI target component. However, unlike Williams' (1990) 30-s no-signal condition, birds in Group 1 showed no evidence of anticipatory contrast when target- and following-component durations were identical. Therefore, data from Group 1 suggest that anticipatory contrast does not develop when target-component responding is unreinforced.

Anticipatory contrast emerged for 6 of 8 birds in Groups 2 and 3 as target-component duration was lengthened. Unlike the data reported by Williams (1989, 1990), the magnitude of anticipatory contrast did not vary inversely with target-component duration. Rather, in Group 3 anticipatory contrast was obtained at long (18 and 30 s) but not at short (6 and 12 s) component durations. Because rate of reinforcement varied with component duration in the present study, the generality of Williams' data is not seriously challenged.

There are two likely sources of the obtained covariation in reinforcement rate and component duration in the present study. First, the low rates of responding obtained under two of the short-component-duration conditions (Phases 6a [C2] and 12) probably contributed to the low reinforcement rate in these phases. Second, cancellation of uncollected reinforcers at the end of each component may have produced a proportionally greater decrement in rate of reinforcement for short versus long components. Because the present research suggests an important role for rate of target-component reinforcement in multiple schedule interaction, future research should involve systematic manipulation of this variable with component duration held constant and uncollected reinforcers held over for the next identical component.

GENERAL DISCUSSION

Collectively, the results of Experiments 1 and 2 indicate that Pavlovian control of target-component behavior can be readily observed

when reinforcement rate during those components is low or zero. This is true even when target-component duration approaches or equals Component 2 duration (Figure 3, Group 1, all contingent phases) and when Component 2 is differentially cued across sequences (Figure 1, Group 3, Conditions C1 and C2). Therefore, target-component duration and differential cuing are eliminated as the source of previous failures to demonstrate the Pavlovian effects reported by Brown et al. (1982). Rather, delivery of reinforcers during target components, either response independently (Farley, 1980) or contingent upon key pecking (Williams, 1976, 1979, 1981, 1990; Wilton & Gay, 1969), emerges as the active variable.

A mechanism by which Pavlovian effects presumably mediate positive behavioral contrast is provided by the additivity hypothesis (Rachlin, 1973), according to which auto-pecks, engendered by the Pavlovian relation, supplement pecks maintained by a prevailing response-dependent schedule to produce an elevation of response rate in a target component. The plausibility of this account received support from demonstrations that behavior controlled by the two independent factors could be spatially separated in two-key procedures (Keller, 1974; Speelman, 1976). However, the possibility of differential reinforcement of changeover responses complicated a two-factor analysis of this technique (Williams, 1983). The present design may be characterized as a temporal separation procedure in which stimuli controlling behavior by presumed Pavlovian and operant relations are isolated temporally but not spatially.

Results of the present and previous research (e.g., Brown et al., 1982) encourage the view that Pavlovian relations control behavior in the presence of initial-component cues. However, the conditions of the temporal separation procedure and those of conventional contrast differ. Positive contrast effects are always measured as an increase in rate of a behavior already under control of an extant reinforcement schedule (usually VI), whereas the present effect is a rate increase under nonreinforcement conditions. Although the mechanism underlying behavior change in both cases could be identical, notwithstanding that procedural variation, the results of the present experiments indicate that the difference is critical. When the target-component schedule is EXT

in both sequences, the conversion of a Component 2 schedule from VI to EXT produces a relative response-rate increase in the target component of the positive sequence; when the target-component schedule is VI, the same manipulation produces the opposite result. Therefore, the role of the present Pavlovian effect in conventional behavioral contrast is questionable.

The mechanism by which target-component reinforcement determined the type of multiple schedule interaction obtained in the present study requires further analysis. By definition, a necessary condition for anticipatory contrast is a target component that signals a transition to a rate of reinforcement lower than that prevailing during the target component. When target components are without reinforcement, this type of transition does not take place. On the other hand, the Pavlovian model of target-component behavior requires only that a higher rate of reinforcement is signaled by a target-component cue than by alternative cues. Reinforcement during target components would contribute to behavior control insofar as it altered the strength of the $S-S^R$ relation between a target cue and schedule of reinforcement in the following components.

Consistent with the foregoing analysis, data from Experiment 1 indicate that Pavlovian effects may be observed regardless of whether reinforcers are earned during the target component signaling a positive transition. As shown in Figure 1 and Table 2, target-component behavior of birds in Groups 1 and 3 varied as a function of the presence or absence of an $S-S^R$ relation between target-component cues and schedule of reinforcement in the following component. Even though birds in Group 3 earned many of the reinforcers available during the target component of the RI sequence, behavior in that component varied reliably with the $S-S^R$ relation across the reversal design. However, data from Experiment 2 indicate that Pavlovian effects may be obscured when the requisite conditions for anticipatory contrast are also met in the four-ply multiple schedule. In that experiment, 6 of the 8 birds in Groups 2 and 3 began to earn a substantial number of reinforcers during the target component of the EXT sequence and were thereby exposed to the conditions under which anticipatory contrast may emerge (see Table 4). All of these birds demonstrated some evidence of anticipatory contrast.

Of particular interest is a comparison of performance under the two 6-s duration conditions (Condition C2 and reinstatement) plotted in Figure 3. Although birds in all three groups showed evidence of Pavlovian control during Condition C2, under which rate of obtained reinforcement in the EXT target component was extremely low for all birds (see Table 4), this effect was recovered only for birds in Group 1, during the reinstatement of the 6-s condition. Six of 8 birds in Groups 2 and 3 showed high rates of responding and earned reinforcement in both target components. The loss of Pavlovian control for those groups may be understood as arising in part from the attendant degradation of the $S-S^R$ relation as well as the emergence of conditions favoring anticipatory contrast. Because number of earned reinforcers in Component 1 varied directly with Component 1 duration for the latter groups, the opportunity afforded at longer durations for behavior to contact the lean VI schedule of reinforcement may have had the major effect, rather than any potential influence of Component 1 duration on the strength of the $S-S^R$ relation.

The results of Experiment 1 (Group 1) join those of previous research (Brown *et al.*, 1982; Marcucella, 1981; Ortega & Marcucella, 1987) showing substantial control of key pecking by an $S-S^R$ relation in the presence of a cue explicitly unpaired with reinforcement. The phenomenon may be treated theoretically as an instance of trace conditioning (Balsam, 1984; Ortega & Marcucella, 1987), but its robustness requires that any formulation of the $S-S^R$ relation must relax the requirement of $S-S^R$ contiguity that prevails in current theory.

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